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BATSE Observations of BL Lac Objects

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Abstract. The Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory has been shown to be sensitive to non-transient hard X-ray sources in our galaxy, down to flux levels of 100 mCrab for daily measurements, 3 mCrab for integrations over several years. We use the continuous BATSE database and the Earth Occultation technique to extract average flux values between 20 and 200 keV from complete and radio- and X-ray- selected BL Lac samples over a 2 year period.

1. Introduction

BL Lac objects have been studied throughout the electromagnetic spectrum; from radio to TeV gamma rays each energy band has provided clues to the energy production mechanisms at the source. The lower energy part of a BL Lac spectrum is thought to be synchrotron radiation of relativistic electrons in a jet oriented at a small angle to the observer, and the higher energy emission Inverse Compton (IC) scattering by the electrons either of these same photons or photons external to the jet,

The position of the peak in the synchrotron emission is often used to differentiate between two classes of BL Lac objects - low-frequency (LBL) and high-frequency (HBL) - the two classes correspond roughly to those first detected in radio (RBL), and those selected in X-ray measurements (XBL) respectively. The distinctions between the classes, however, are not always clear. Sambruna et al. (1996) find that a subclass of LBLs look like HBLs viewed from a closer angle to the jet i.e. their soft X-ray spectrum is dominated by synchrotron (like HBLs) but flat enough to suggest an IC component (like LBLs). They suggest that in general a flatter component becomes apparent in the spectra of LBLs above 1 keV which may signify the start of the IC scattered component. The corresponding IC spectrum of HBLs starts at tens of keV, but there appear to be transition BL Lacs which exhibit properties of both classes. This points toward there being a combination of beaming and intrinsic continuum of behaviours rather than two distinct classes.

Studying BL Lac objects in the X-ray energy band gives us a window into the synchrotron to Compton turning point. BATSE provides the opportunity to monitor many BL Lacs over a long time line in hard X-rays. This reduces the problems of poor sampling, source flux variability and spectral variability. Examination of the Piccinotti sample of AGN (which includes 4 HBLs) with BATSE data between 20 and 100 keV over a three year period (Malizia et al. 1998) showed that BATSE is sensitive to at least some of these objects. We present here a preliminary analysis of two years of BATSE data for the X-ray Einstein slew survey (Perlman et al. 1996), and the complete 1 Jy radio-selected sample (Stickel et al. 1991).

2. BATSE observations.

The BATSE Large Area Detector (LAD) data consist of counts in 16 energy channels between 10 keV and several MeV. BATSE detects persistent emission from hard X-ray sources by looking at changes in the continuous LAD background rates when the source rises from and sets behind the Earth (Earth Occultation Technique (Harmon et al. 1992). In the $\sim$ 90 minute CGRO orbit, each source will contribute two steps, one each from a rise and a setting. The weakness of BL Lac sources requires the summing of many steps - in general one needs integration times of several months to a year to extract a signal, although flaring activity can be seen on time-scales of days, at least in the case of MRK501 (Connaughton et al. 1998). A BATSE survey of 34 supernova remnants (McCollough et al. 1992) indicates that the sensitivity of the technique over a long time line (nearly 5 years) is about 3 mCrab.

Although steps from known bright sources are measured and fit in the Earth Occultation technique, non-statistical fluctuations in the resultant lightcurves suggest careful cleaning of the data is necessary before making any flux estimates. Data were cleaned by (i)checking for and flagging spacecraft pointing-dependent fluctuations due to contaminating sources in the limbs to the source and (ii)removing outlier individual occultation steps to reduce systematic errors. These outliers are usually attributable to pulsar activity in individual detectors. Fifteen blank fields which were randomly generated and selected only if they were devoid of known strong X-ray sources were included in the occultation analysis. The proximity and number of bright, interfering sources in the blank fields can be judged by the recurrence of interference patterns in the lightcurves as the orbit of the spacecraft precesses and the relative geometries of source and interferer recur. It was seen that sources closer than 5° to the galactic plane, or within a cone 45° around the galactic center up to a latitude of 30° are particularly vulnerable to contamination. The 5 BL Lac sources and 4 blank fields which fall in this region are difficult to resolve from the numerous brighter galactic sources even with careful cleaning and have been removed from the analysis. In the remaining blank fields which had no visible contamination, the distribution of the significance of flux estimates was symmetrical, but clearly non-Gaussian. The errors on flux measurements were increased by 65% of the value of the statistical error to account for the presence of systematic errors.

Table 1 shows the flux estimates over the first 2 years of the BATSE mission in the energy range between 20 and 200 keV where the background fitting in step calculations is most accurate and the response of the detectors is efficient.

A photon index of -2.0 was used in the conversion of counts to photons when folding the counts through the detector response. The flux errors are statistical but the significances are based on the total error. A 3σ excess corresponds to a flux level of $\sim 8 \times 10^{-11}$ erg cm^{-2} s^{-1}. No blank fields showed an excess at this significance level, while 9 of the BL Lacs were detected. Of these 9 detections, 2 (1144-379 and 1147+245) are questionable because the fluxes measured in the rising and setting limbs were not consistent at a $2\sigma_{stat}$ level.

There is no correlation between BATSE flux and redshift, galactic latitude, or soft X-ray flux. If one characterizes each object according to its degree of "HBL-likeness", the ratio of the X-ray flux at 1 KeV and the radio flux at 5 GHz, where $log(F_x/F_r) = -5.5$ is the common dividing line between LBL and HBL, one finds that while BATSE appears sensitive to both HBL and RBL, the flux detected in the HBL appears greater. Clearly, one needs more detections to quantify this in a meaningful fashion.

This analysis is being applied to more samples of BL Lacs and to examine the remaining 5 years of BATSE archival data. Detection of LBLs, HBLs and the intermediate BL Lacs (Laurent-Muehleisen et al. 1997) in significant numbers may allow to to distinguish (by fitting spectra to the count rates rather than assuming a -2.0 power law) between the hypotheses of (i)different IC components for distinct populations and (ii)BL Lacs forming one family showing a continuum of properties.

3. Variability

The detection by BATSE of a hard X-ray Mrk 501 flare with a flat spectrum out to at least 100 keV opens the possibility that BATSE will be able to detect some sources in high intensity states over time-scales of days. If these flares are discovered as they are happening, BATSE might be used as a monitor for strong, hard flares - multi-wavelength flare campaigns could be initiated providing the detection is convincing. A preliminary search of the 1991-93 database for day-scale flares (for all 87 sources) of magnitude equal or greater than that seen in Mrk 501 in April 1997 yields only one convincing detection: again, the object is Mrk 501. It is clear that a more systematic search for longer time-scale flaring may be fruitful. One can see in Table 1 that while the blank field excess distributions are symmetrical, there are far more $+2\sigma$ excesses than -2σ deficits in the BL Lac samples, and many more than expected by chance. Since these sources have exhibited variability over most time-scales at all wavelengths at which they have been monitored, it is expected that those sources which may not prove significant over integrations of 2 years might be active on shorter time-scales. This analysis is in progress.

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Table 1. Average BATSE fluxes 20-200 keV between 1991 and 1993

Source	Flux $\times 10^{-11}$ erg cm^{-2} s^{-1}	N_σ	Source	Flux $\times 10^{-11}$ erg cm^{-2} s^{-1}	N_σ
blx0507-040	-8.13 ± 1.51	-3.26	blx1517plus656	3.25 ± 1.79	1.1
blank 13	-6.22 ± 1.48	-2.54	blx0158plus003	2.53 ± 1.37	1.11
blx2343-151	-3.85 ± 1.42	-1.64	blr0851plus203	2.67 ± 1.38	1.17
blx0715-259	-3.64 ± 1.47	-1.5	blx2005-489	2.97 ± 1.52	1.18
blank 4	-3.44 ± 1.44	-1.44	blx1727plus502	3.37 ± 1.7	1.2
blank 3	-4.05 ± 1.88	-1.3	blx1248-296	3.11 ± 1.56	1.2
blank 5	-2.94 ± 1.44	-1.23	blx0502plus675	3.69 ± 1.79	1.24
blr2131-021	-2.37 ± 1.42	-1.01	blx1028plus511	3.52 ± 1.61	1.32
blank 11	-2.37 ± 1.45	-0.99	blx1553plus113	3.47 ± 1.58	1.33
blr0454plus844	-2.14 ± 1.75	-0.74	blr1308plus326	3.22 ± 1.46	1.33
blr0235plus164	-1.66 ± 1.42	-0.7	blr0820plus225	3.18 ± 1.4	1.37
blr0048-097	-1.54 ± 1.39	-0.67	blx1959plus650	4.47 ± 1.9	1.42
blank 12	-1.56 ± 1.43	-0.66	blx1101plus384	3.4 ± 1.44	1.43
blr0138-097	-1.13 ± 1.39	-0.49	blr0537-441	3.74 ± 1.54	1.47
blx0806plus524	-1.3 ± 1.64	-0.48	blank 8	3.59 ± 1.43	1.52
blx1215plus303	-1.04 ± 1.59	-0.39	blr1418plus546	4.33 ± 1.68	1.56
blx1239plus069	-0.78 ± 1.45	-0.32	blr1807plus698	5.41 ± 1.95	1.68
blx0548-322	-0.771 ± 1.46	-0.32	blr2254plus074	4.01 ± 1.37	1.77
blx0347-121	-0.592 ± 1.48	-0.24	blx0323plus022	4.15 ± 1.42	1.77
blx1312-423	-0.61 ± 1.66	-0.22	blx1853plus671	5.55 ± 1.88	1.78
blx1544plus820	-0.259 ± 1.88	-0.08	blr0823plus033	4.42 ± 1.43	1.87
blr1823plus568	-0.152 ± 1.78	-0.05	blx1332-295	5.31 ± 1.6	2.01
blx0145plus138	0.0719 ± 1.39	0.03	blx0219plus428	5.32 ± 1.57	2.05
blx0414plus009	0.299 ± 1.49	0.12	blank 14	5.83 ± 1.67	2.11
blx0525plus713	0.431 ± 1.84	0.14	blx2321plus419	5.73 ± 1.54	2.25
blx1218plus285	0.663 ± 1.57	0.25	blx0229plus200	5.33 ± 1.42	2.27
blr2240-260	0.616 ± 1.43	0.26	blr2007plus777	7.57 ± 1.99	2.3
blx0950plus495	0.678 ± 1.57	0.26	blx1440plus122	5.51 ± 1.43	2.33
blr0716plus714	1.01 ± 1.8	0.34	blx2155-304	5.41 ± 1.4	2.34
blx2326plus174	0.864 ± 1.37	0.38	blx0927plus500	6.15 ± 1.57	2.37
blank 6	1.17 ± 1.65	0.42	blr2200plus420	6.23 ± 1.55	2.43
blr0814plus425	1.09 ± 1.5	0.44	blx2344plus514	6.8 ± 1.67	2.46
blr0735plus178	1.23 ± 1.43	0.52	blx0647plus250	6.15 ± 1.47	2.53
blr0828plus493	1.4 ± 1.58	0.53	blr0954plus658	7.45 ± 1.74	2.59
blank 10	1.56 ± 1.7	0.55	blr1514-241	6.4 ± 1.49	2.6
blx1101-232	1.49 ± 1.5	0.6	blx0737plus746	8.06 ± 1.86	2.62
blank 2	1.58 ± 1.56	0.61	blr0118-272	6.59 ± 1.41	2.83
blx1118plus424	1.57 ± 1.54	0.61	blr1147plus245	7.6 ± 1.51	3.05
blx1320plus084	1.49 ± 1.42	0.63	blr1803plus784	10.4 ± 2.01	3.13
blx1218plus304	1.76 ± 1.6	0.66	blr1538plus149	8.26 ± 1.57	3.18
blx1106plus244	1.73 ± 1.49	0.7	blr1144-379	8.09 ± 1.52	3.22
blr0426-380	1.78 ± 1.47	0.73	blx1652plus398	9.28 ± 1.59	3.53
blx1011plus496	1.97 ± 1.58	0.75	blx1255plus244	9.03 ± 1.47	3.72
blx1133plus704	2.54 ± 1.81	0.85	blx1212plus078	9.88 ± 1.48	4.04
blx1402plus042	2.08 ± 1.4	0.9	blx1426plus428	10.9 ± 1.54	4.28
blx1421plus582	2.71 ± 1.75	0.93	blx0120plus340	12.5 ± 1.46	5.18
blx1533plus535	2.95 ± 1.68	1.06			